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The Role of Vaccination in the Control of SARS

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Summary

Severe acute respiratory syndrome (SARS) is a viral respiratory illness caused by SARS coronavirus (SARS-CoV). The first cases were reported in the Southern China Province of Guangdong [**?**]. The 2003 epidemic was driven by international travel and lack of knowledge of its etiological agent. The World Health Organization reported 8,422 cases with 916 deaths as of August of 2003. Containment of the SARS epidemic was possible by rapid diagnosis and effective isolation of infectious cases.

SARS symptoms include high fever, headaches, body aches, mild respiratory symptoms at the outset, diarrhea, and usually a development of a dry cough within seven days of infection [**?**]. Most SARS patients develop pneumonia [**?**]. SARS is transmitted by close person-to-person contact [**?**]. The mean incubation period for SARS (the period that a person is infected but not infectious) is approximately 6.4s days [**?**]. Suspected cases are hospitalized at rate $1/4.85$ days^{-1} and recovered individuals leave hospitals on average 23.5 days after diagnosis, or die on average 35.9 days after diagnosis [**?**].

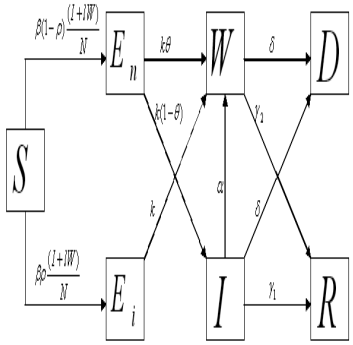
We assess pre-outbreak and during-outbreak vaccination as control strategies for SARS epidemics. Our model includes susceptible, latent (traced and untraced), infectious, quarantined/isolated and recovered classes. We take parameter estimates from published literature.

We explored different scenarios for control including the effects of levels of pre-outbreak successfully vaccinated individuals as the number of secondary cases by a primary infectious case (R_0) and the final epidemic size.

The basic reproductive number is given by

$$R_0(\sigma) = \beta(1-\sigma)\left(\frac{(1-\rho)l\theta}{\delta+\gamma_2} + \frac{(1-\rho)l(1-\theta)\alpha}{(\delta+\gamma_2)(\alpha+\delta+\gamma_1)} + \frac{(1-\rho)(1-\theta)}{\alpha+\delta+\gamma_1} + \frac{\rho l}{\delta+\gamma_2}\right).$$

Assuming 40% of quarantine and isolation individuals contribute to new infections throughout an outbreak, a large number of cumulative cases occur even when vaccination is implemented. In this case, a significant reduction in total cumulative cases is observed after at least 27% of the initial population is vaccinated. Higher vaccination rates do not affect the percentage of cumulative cases as significantly, but have an impact in the reduction of the to-



The population of susceptible is reduced through the successful vaccination of a proportion σ before the outbreak. E_n are the untraced latent (infected, not infectious) individuals and E_i are the traced latent individuals. The class I denotes the infectious, untraced individuals, while the class W denotes the diagnosed, infectious individuals placed into quarantine/isolation who were given supportive treatment. D and R denote the dead and recovered classes, respectively. For parameter descriptions see Table **??**.

Parameter	Definition	Baseline Value	Ref
β	Transmission rate per day	0.25	[**?**]
$1/k$	Mean incubation period (days)	6.37	[**?**]
$1/\gamma_1$	Mean infectious period (days)	28.4	[**?**]
$1/\gamma_2$	Mean infectious period for diagnosed individuals (days)	23.5	[**?**]
$1/\alpha$	Mean period before diagnosis (days)	4.85	[**?**]
δ	Disease induced death rate per day	0.0279	[**?**]
σ	Proportion of susceptibles successfully vaccinated	$[0,1]$	
ρ	Proportion of latent population traced	$[0,1]$	
θ	Proportion of untraced latent that self-quarantine	$[0,1]$	
l	Effectiveness of quarantine/isolation	$[0,1]$	[**?**]

Parameter definition and baseline values for the model parameters.

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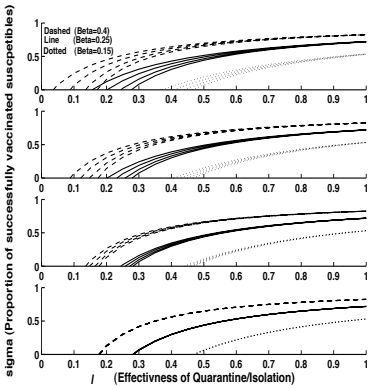

$R_0(\sigma, l) = 1$ *boundary curves for* $\beta = [0.15, 0.25, 0.40]$ *to determine the critical vaccination coverage as a function of the quarantine/isolation effectiveness. As* β *increases, the minimum* σ *needed to control an outbreak increases.*

tal epidemic size. Thus, when quarantine/isolation is constant, pre-outbreak vaccination plays an important role in the reduction of the total cumulative cases.

However, with improvements in quarantine/isolation effectiveness throughout an outbreak, pre-outbreak vaccination does not play such a major role in reducing the total cumulative cases. While the total epidemic size is reduced as σ increases, this reduction is not as significant as in the case of constant $l = 0.4$. Assuming constant quarantine/isolation effectiveness of $l = 0.4$, in the case of a sudden outbreak of SARS when no pre-outbreak vaccination can be implemented, during-outbreak vaccination reduces the total epidemic size. The efficacy of the vaccine, ε, is assumed to be at least 50%, but not more than 90%, and the rate at which people are vaccinated is $0.2 \leq \chi \leq 0.5$. If the efficacy of the vaccine and the rate at which susceptibles are vaccinated increases, the number of cumulative cases decreases. Implementing during-outbreak vaccination sooner into the outbreak, the number of cumulative cases decreases more significantly compared to when vaccination starts later into the outbreak. However, if pre-outbreak vaccination is implemented, then during-outbreak vaccination does not affect the total epidemic size at all. Efforts should also be spent on tracing people after the start of the outbreak. In the case of constant quarantine and isolation effectiveness of $l = 0.4$, pre-outbreak vaccination needs to be implemented to reduce the total cumulative cases, and if vaccination before the outbreak is not possible then vaccination should be implemented as soon as possible into the outbreak.

Acknowledgements

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